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THE ENERGY BUDGET AT THE EARTH'S SURFACE: ORIGINS OF SHORT-TIME CO_2 FLUCTUATIONS IN A CORNFIELD

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INTERIM REPORT

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INTERIM REPORT

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Prepared by

E. R. Lemon, James L. Wright and George M. Drake

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ORIGINS OF SHORT-TIME CO_2 FLUCTUATIONS IN A CORNFIELD

E. R. Lemon, James L. Wright, and George M. Drake

SAMPLING PROCEDURE FOR CO_2

It has long been known that the CO_2 content of the air near the earth's surface undergoes temporal and spacial fluctuations arising from inhomogeneous distributions of sources and sinks of carbon dioxide as well as the degree of air mixing by meteorological processes (Huber, 1952). The fluctuations can present serious sampling problems when one is attempting to obtain representative values for the carbon dioxide content of the air. We have found this especially true in our studies of CO_2 exchange above active plant communities.

Despite the fact that we have been well aware of the shorter time fluctuations of the order of 1/4 to 2 cycles per minute and as a consequence have taken pains to obtain integrated samples for 10-to 20-minute sampling periods, no attempts were ever made to study the short-time fluctuations themselves. We would like to report now on such a study in a full-grown field of corn.

A description of the site has been published elsewhere (Lemon, Shinn and Stoller, 1963). Nonetheless certain features are pertinent to this study. One is the fact that the cornfield was relatively isolated as a frost-sensitive crop in an area of mixed vegetation of relatively frost-hardy species. Another fact of importance is that the wind fetch over the corn to the sampling site was of the order of 100 meters. The significance of these two points will be discussed later.

Two sampling procedures for CO_2 were followed: (a) during all but one of the six sampling periods, time and space integrated samples were collected, stored and subsequently analyzed to provide mean vertical profiles of CO_2 concentration above and within the crop. The procedure has been reported in detail elsewhere (Lemon and Wright, 1967). In the present study profile samples were taken at the following heights; 380, 225, 135, 95, and 35 cm above the ground. The profiles obtained, which are identified by time, are presented in the left side of Figure 1.

(b) Simultaneous to the collection of samples for a given mean profile, sampling and analytical procedure provided a continuous record of the fluctuating carbon dioxide content of the air at a single point above the ground. There were six "runs" of about 10-minute duration each, with the "fluctuation" samples being taken in turn at the following levels above the ground; 520, 424, 305, 216, 140 and 51 cm. The corn was 285 cm tall at the time with the uppermost large leaves at about

225 cm, thus three fluctuation samples were taken above the vegetation and three within the canopy. The data are presented in the right side of Figure 1 as fluctuations from the mean for the sampling period. Each sample is identified by level above the ground and time in association with a particular mean vertical profile.

Further details of the continuous recorded samplings are pertinent. A single 50-meter length of 0.5 cm ID PVC tubing attached to the suction side of an aquarium pump provided sample air direct to an infrared CO_2 gas analyzer. The inlet of the tubing was supported on a mast in the corn located upwind from the instrument trailer in which the pump and analyzer were located. The inlet of the tube was positioned in sequence on the mast at a given sampling level beginning at the top. The tubing from the mast to the trailer was strung on corn leaves through the crop at about 150 cm above the ground to prevent the tubing from lying on the ground. This minimizes errors caused by possible diffusion of CO_2 into the tubing from the higher concentrations of CO_2 found near the ground. Also higher daytime temperatures near the ground favor the evolution of organic gases out of the tubing creating additive errors in measurement by infrared methods. Both of these errors were minimized by a rapid air sampling rate. Since emphasis here is on the fluctuations over a short time period, such errors are likely to be of no significance. Giving substance to this belief is the fact that after the corn was killed by a frost the fluctuations disappeared, indicating that the fluctuations were indeed caused by conditions external to the sampling system.

The aquarium pump delivered air at a constant rate of 2.5 liters per minute. The exhaust side of the pump led directly into a special carbon dioxide infrared analyzer having a range of $\pm$ 12.5 ppm with a sensitivity of $\pm$ 0.2 ppm. Other details of the instrument are reported elsewhere (Wright and Lemon, 1966).

Before starting a run the sampling airstream was split entering the analyzer in two streams, one going through the "sample cell" and the other through the "reference cell", both exhausted to ambient atmospheric pressure. In this way "zero" differential was established with air of like composition in each cell (i.e. both in CO_2 and water vapor). When a run was started the "reference cell" was closed off and the sample air continuously put through the "sample cell" only. Thus the continuous fluctuations were relative to the air composition at the beginning of a run. The analyzer has sufficient discrimination between water vapor and carbon dioxide such that when used in this way it is not necessary to remove the water vapor.

Before the study was begun it was important to determine the instrument response time. By putting a square wave concentration differential through the analyzer, using standard gases, we were able to establish that

complete equilibrium is reached in 10 seconds at a flow rate of 2.5 liters per minute. Thus the instrument itself is capable of "seeing" at least 6 cycles per minute.

The problem of sample "smearing" during flow through the tubing before reaching the analyzer is a serious complication to be reckoned with. This problem was investigated by passing "square wave" differentials of CO_2 concentration through sampling lead-in tubing under variables of tubing composition, tubing diameter, tubing length and air stream velocity. The results are presented in Figures 2 and 3. From studying Figure 2 we can approximate the essential characteristics of the system used in the fluctuating sample study. It will be observed that with 46 meters of 0.5 cm tygon tubing and a flow rate of 1 liter per minute it took 71 seconds to register a change in CO_2 concentration and an additional 30 to 35 seconds to reach 95% equilibrium. One could anticipate that with a flow rate of 2.5 liters a minute through 50 meters of 0.5 ID PVC tubing the initial lag would be about $(\frac{1}{2.5} \times 71 \text{ sec})$ 30 seconds and that it would take considerably less than 30 additional seconds to reach 95% equilibrium. Thus as a conservative estimate the complete system should "see" fluctuations as frequent as 4 cycles per minute. Frequencies of greater than 4 cycles per minute are filtered out by the lead-in hoses. Returning to Figure 1 it is obvious that the fluctuations appear to be for the most part, of lower frequency. They are roughly 1/4 to 1 cycle per minute.

We now should turn to the problem of the velocity of air flow during the study. We can only present mean velocities for the six sampling periods. They are to be found in Table 1. The methods of obtaining these results are discussed by Lemon and Wright, 1967.

Inspection of Table 1 will indicate that there was a gradual decrease in general wind flow as the afternoon progressed. However, this is of minor importance compared to the decrease in wind due to position above and in the canopy. Thus in inspecting Figure 1 the increase in amplitude of the CO_2 fluctuations with approach to the ground can be associated with a decrease in wind velocity caused primarily by canopy resistance.

Because of the scale of height of measurement and the filtering out of frequencies greater than four cycles per minute, it is doubtful that any change in frequency of CO_2 fluctuation with height can or should be detected.

We are now at a point where it may be appropriate to speculate about the origins of the low frequency fluctuations observed.

When this phenomenon was first observed by us several years ago at the same site we reasoned that the fluctuations were created outside the field because the eddy scale was larger than the upwind fetch in the field. For example, at a low mean wind flow of 1 meter/sec just above the canopy and a 1/2 cycle per minute fluctuation, the eddy scale would be 120 meters (1 meter/sec x 60 sec/min x 1/2). At a moderate wind of 2 or 3 meters/sec the eddy scale would be 240 to 360 meters, considerably greater than our 100 meter fetch in the cornfield.

However, two findings in this study have caused us to question our earlier reasoning: (1) three days following the fluctuation study the corn was thoroughly killed by a frost causing a subsequent cessation of CO_2 fluctuation at all levels. Yet the surrounding frost hardy vegetation appeared to be unharmed by frost; (2) the frequency of fluctuation before frost appears to be independent of height despite the wide range of windspeed.

From these we now speculate that the CO_2 fluctuations are indeed created in the cornfield by sources and sinks originating there due to photosynthesis and respiration. Further, the eddies creating the fluctuations could be originating either inside or outside the field or both. In any case, they have to be moving across the field at a much slower velocity than that of the mean windspeed. Also nothing can be inferred about their size or shape. Now we need to make simultaneous fluctuation measurements at several horizontal and vertical points to throw light on this phenomenon.

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Table 1. Mean wind velocity at various levels above and within a canopy of corn (cm/sec). Ellis Hollow, N. Y. September 18, 1963.

Time (EST)	Height above ground, cm					
	520 cm	424 cm	305 cm	216 cm	140 cm	51 cm
1358-1408	<u>272</u>	241	187	99	32	14
1435-1445	227	<u>202</u>	156	82	27	11
1510-1520	205	182	<u>141</u>	74	24	10
1545-1555	218	193	150	<u>79</u>	26	11
1615-1625	141	125	97	51	<u>17</u>	7
1645-1655	138	122	95	50	16	<u>7</u>

Height of corn was 285 cm.

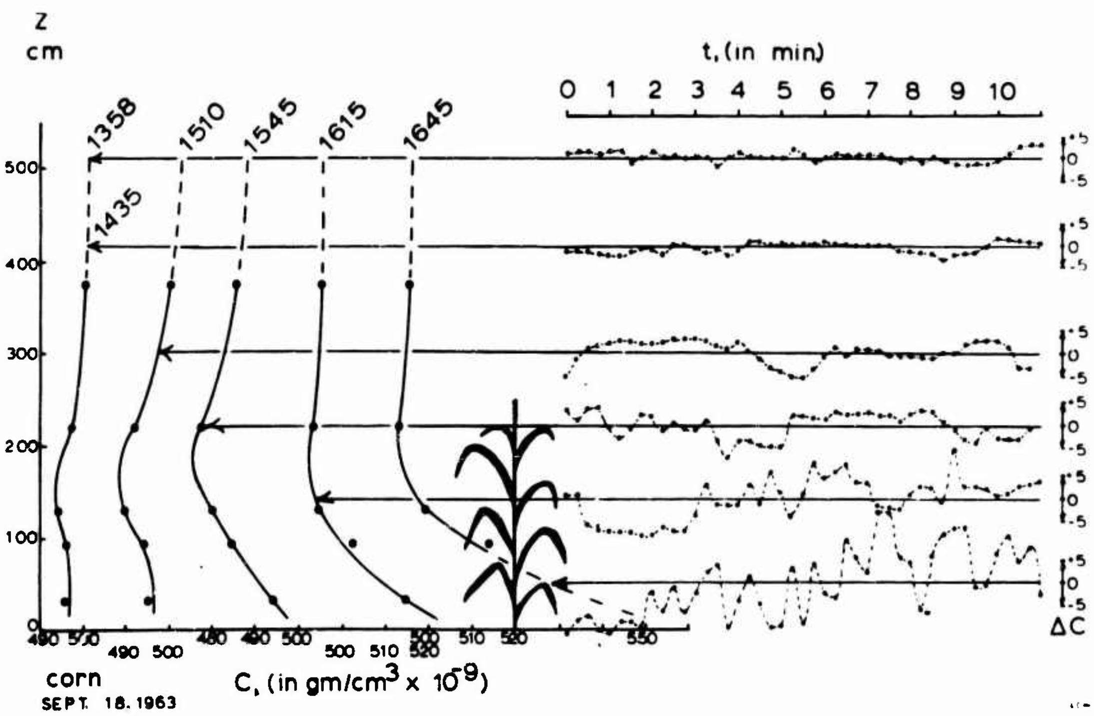

Fig. 1. Mean CO_2 concentration ($\bar{C}$) profiles in a cornfield for the indicated time and the variation (Δc) from the mean during the 10-minute sampling period for each specific time and level as indicated by arrow. Ellis Hollow, N.Y.

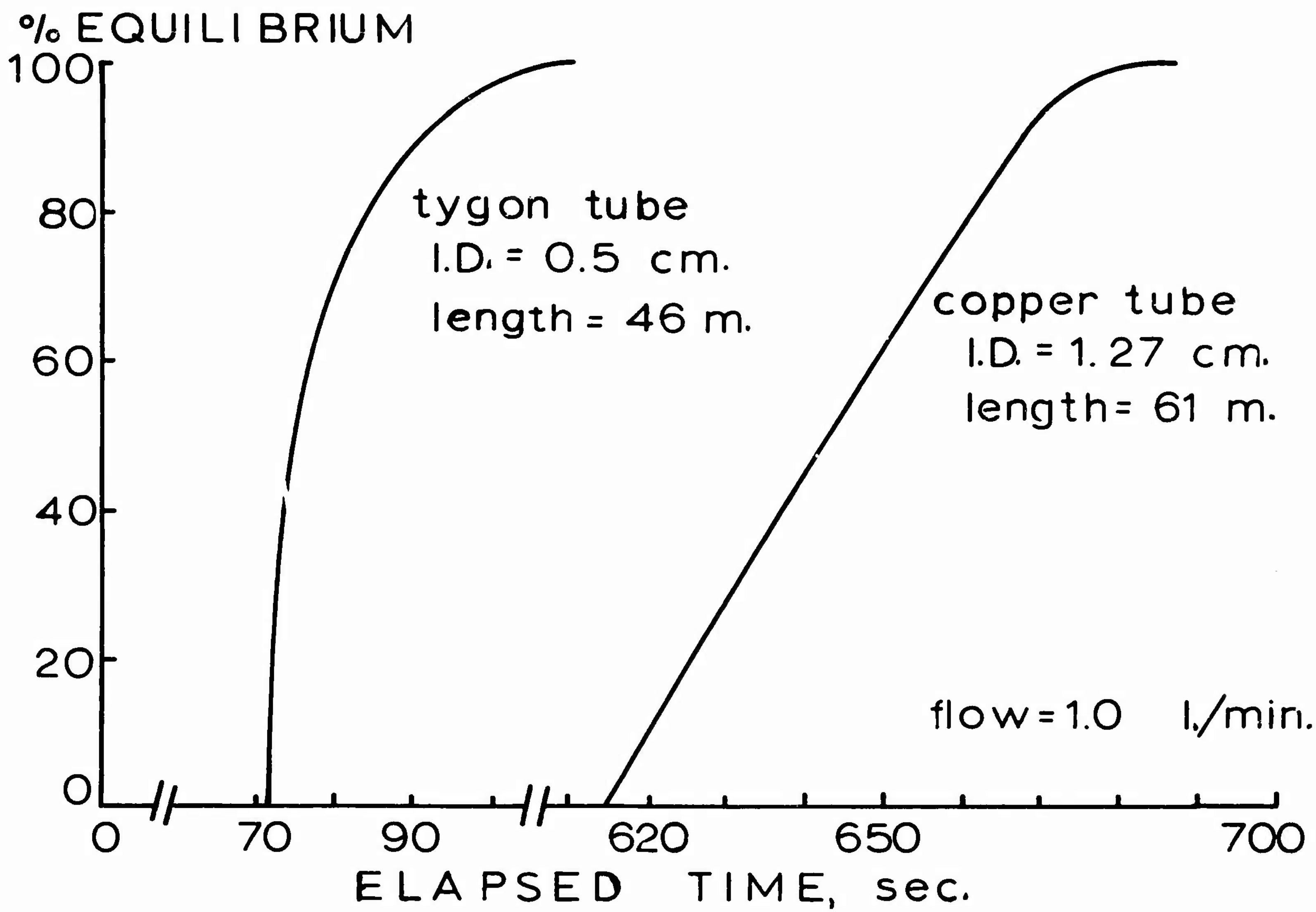

Fig. 2. CO_2 sampling plus analytical system response characteristics to a square wave input of CO_2 differential of 3 ppm in air at a flow rate of one liter per minute.

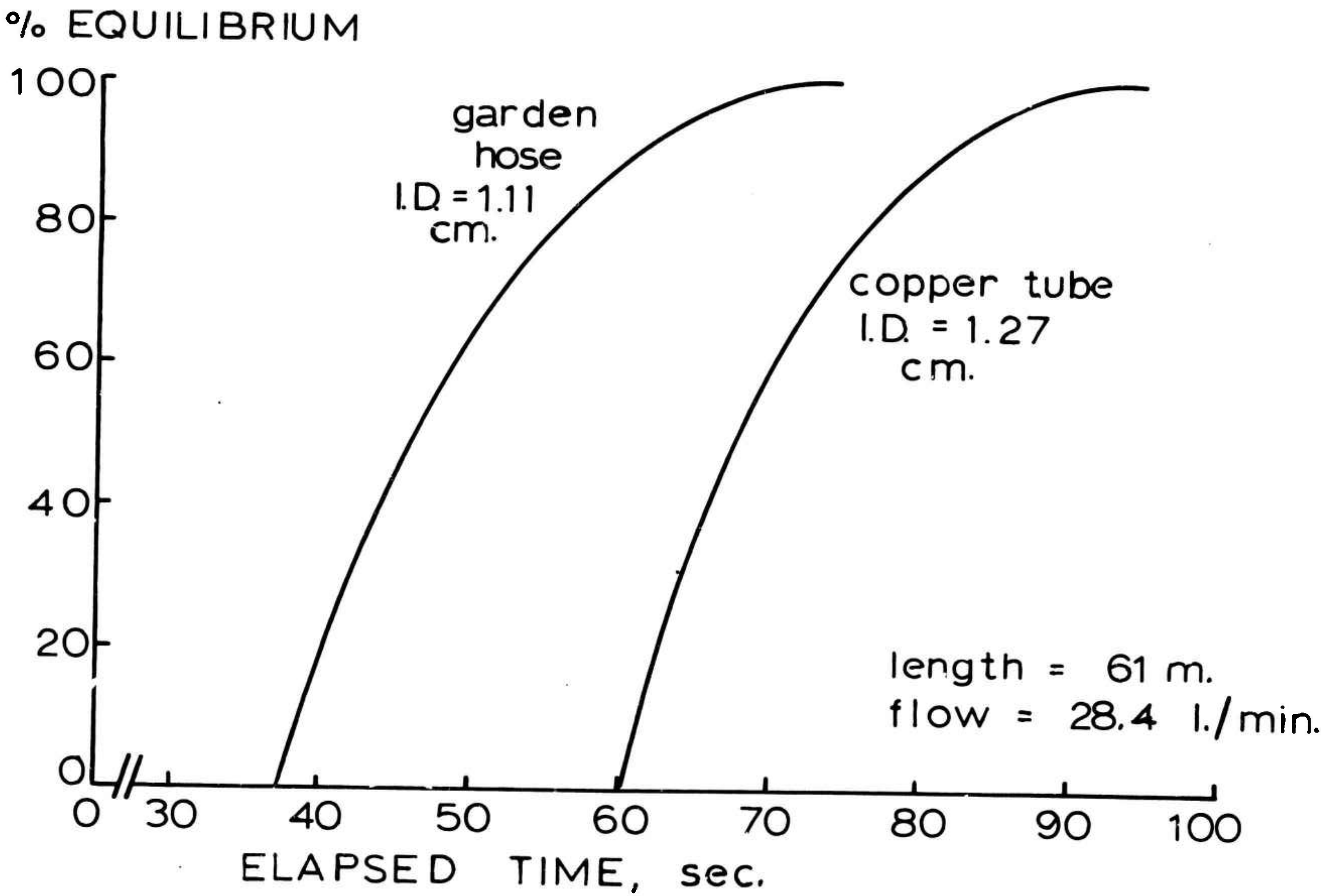

Fig. 3. CO_2 sampling plus analytical system response characteristics to square wave input of CO_2 differential of 15 ppm in air at a flow rate of 28.4 liters per minute.

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13. ABSTRACT

Studies of the vertical distributions of CO_2 fluctuation in a cornfield were made in the 4 to 0.25 cycle/minute frequency range. Amplitude of fluctuations decreased with height above the ground. Frequency in this range appeared rather constant, however. Sources and sinks for CO_2 within the cornfield contribute in part to the fluctuations. However, eddy structure originating inside and/or outside the cornfield plays an important role too.

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